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LANGLEY 24-INCH HIGH-SPEED TUNNEL

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NACA LANGLEY MEMORIAL AERONAUTICAL LABORATORY MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces and the

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MR No. L6A08

CALIBRATIONS OF SERVICE PITOT TUBES IN THE

LANGLEY 24-INCH HIGH-SPEED TUNNEL

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SUMMARY

Calibration tests have been made in the Langley 21,-inch high-speed tunnel on a Kollsman type G-1 and an NAF No. 1 pitot tube at an angle of attack of 0° over a Mach number range from 0.20 to 0.87. Additional calibration tests were made on the NAF No. 1 pitot tube at various angles of attack over a Mach number range from 0.20 to 0.53.

The effect of drain holes on the flow within a service pitot tube at 0° angle of attack was analyzed and a relation was derived whereby the error in total pressure could be estimated. This analysis was extended to include the effects of compressibility on the error so that an estimated value or an experimentally determined value could be extrapolated to higher speeds. The calibration tests indicate that the accuracy of the extrapolated and estimated values are within reasonable limits.

INTRODUCTION

Calibration tests have been made on one service pitot tube (Kollsman type G-1) supplied by the Army Air Forces, and on one pitot tube supplied by the Navy and designed for service installations. The tests were conducted in the Langley 24-inch high-speed tunnel.

Tests of the Kollsman type G-1 pitot tube were requested by the Army because of reported erroneous

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total-pressure indications encountered in flight during dives, and because a high-speed calibration of the instrument had not been made. Data previously obtained on similar instruments (reference 1) show that the error in total pressure (in percent of the difference between total and static pressures) is not appreciably affected by Mach number.

If the pressure indicated by the pitot tube installed on an airplane is in error under dive conditions, it is most probable that this error is a result of exceeding the useful angular range of the instrument. The angular range of acceptable accuracy would be greatly reduced if the nose of the instrument is located too close to the leading edge of the wing, because in that region changes in direction of air flow are much greater than changes in angle of attack of wing. Instruments have been installed with the nose 10 inches ahead of the leading edge of the wing.

For the stated conditions, wind-tunnel calibration tests of the instrument alone, even though made over a wide angular range, could not be expected to provide a complete solution to the problem, which could be better studied by comparing in flight the reading of the service pitot tube with that of an instrument capable of determining the correct total pressure over a large angular range. (See reference 2.)

Abrupt changes in the indicated airspeed under landing conditions had been reported for some instrument installations on Naval aircraft. This trouble was believed to be directly related to the variation in the error of the measured total pressure with angle of attack. The Navy therefore designed the NAF No. 1 pitot tube incorporating a Kiel type nose which was expected to measure the total pressure to an accuracy of 1 mile per hour over an extended angular range. The Kiel type instrument (reference 2) is a pitot tube enclosed within a tubular shield, the purpose of which is to maintain alinement between the pitot tube and the flow through the shield. The instrument is thus capable of measuring total pressure without error over a large angular range. The use of a Kiel type nose on the NAF No. 1 pitot tube without allowing flow through the instrument except as provided by the drain holes should not be expected to increase its angular range for zero error over that of a simple total-pressure tube, which is approximately ±130 (reference 3).

A method is given in this report whereby the error caused by the drain holes in a pitot tube at 0° angle of attack can be estimated. The analysis was extended to include the effects of compressibility on the error so that an estimated value or an experimentally determined value could be extrapolated to higher speeds.

A test program was determined in a conference attended by Mr. G. A. Harding of the Philadelphia Navy Yard, Lt. R. Munnikhuysen of Wright Field, and members of the Langley Laboratory staff. In accordance with this program, tests were made on the Kollsman type G-l and the NAF No. 1 (Weigand manufactured) pitot tubes at 0° angle of attack over a Mach number range extending from 0.20 to 0.87. Additional tests were then made on the NAF No. 1 pitot tube at various angles of attack over a range of Mach numbers from 0.20 to 0.53.

METHODS AND APPARATUS

The Langley 21-inch high-speed tunnel in which these tests were made is an induction-type wind tunnel without return passages, having its induction nozzle downstream from the test section.

The total pressure at the test section for all speeds is equal to the atmospheric pressure except for a small loss through screens. This loss, for which the data reported herein have been corrected, has been determined by measurements of the loss through screens and by comparison of the total pressure measured by several total-pressure tubes.

The static pressure in the test section was determined by calibrated static-pressure orifices in the tunnel wall upstream from the test section. The stream Mach numbers and the correct total pressure in the test section were then computed from measured values of the atmospheric pressure and the pressure at the calibrated static-pressure orifices.

The two pitot tubes calibrated and reported herein are:

(1) NAF No. 1
Manufactured by Weigand

(2) Airspeed tube type G-1
Specification No. 94-27378
Kollsman's part No. 781-02

These instruments are shown in figures1(a) and 1(b), respectively.

The pitot tubes were mounted for the calibration tests on a long support tube located approximately in the center of the tunnel. The support tube, having an outside diameter equal to that of the pitot-tube adapter shown in figure 1, formed a rearward extension to the adapter, and was supported by two sets of wires which were fastened to the tunnel walls. Each set consisted of three wires spaced 120° apart. One set of wires was attached to the support tube 3 inches downstream from the adapter, and the other set was 8 inches farther downstream. Figure 2 illustrates this type of mounting.

Changes in the angle of attack were made by rotating the support tube in a plane which passed through the axis of the instrument and the drain holes. The rotation was made so that the nose of the pitot tube retained its location approximately at the center of the tunnel.

SYMBOLS

The symbols used herein are:

- p stream static pressure
- H stream total pressure
- H' total pressure indicated by instrument
- M stream Mach number
- angle of instrument axis with respect to air flow
- Al area of total-pressure duct in region of pressure H'
- A2 area of one drain hole in tube having N equaldiameter drain holes (NA2 is total drain area)

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p, local static pressure at drain hole

V₁ velocity at area A₁

V2 velocity through drain hole

ρ stream mass density (at a static pressure equal to p)

ρ_H stagnation mass density (at a static pressure equal to H)

RESULTS AND DISCUSSION

The error in the measurement of total pressure for a pitot tube at 0° angle of attack resulting from the presence of drain holes can be estimated by using the equation of continuity and Bernoulli's equation for an incompressible flow. Bernoulli's equation is

$$H - p = \frac{1}{2}\rho V^2$$

From which

$$V_1^2 = \frac{H - H!}{\frac{1}{2}\rho}$$

and

$$V_2^2 = \frac{H - p_l}{\frac{1}{2}p}$$

assuming an orifice coefficient of 0.8 the equation of continuity is

$$A_1V_1 = 0.8NA_2V_2$$

eliminating V

$$\frac{H - H!}{H - p_l} = 0.6 L N^2 \left(\frac{A_2}{A_1}\right)^2 \tag{1}$$

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The pressure coefficient for incompressible flow is

$$P = \frac{p_{l} - p}{H - p}$$
$$= 1 - \frac{H - p_{l}}{H - p}$$

Thus

$$\frac{H - H!}{H - p} = 0.64 \text{ N}^2 \left(\frac{A_2}{A_1}\right)^2 (1 - P) \tag{2}$$

This relation shows that the effect of locating the drain hole in a low-pressure or high-velocity region would be to increase the error in the reading. For pitot tubes having drain holes located one or more tube diameters behind the nose, however, the induced velocities at the drain holes would be small. The resulting value of the pressure coefficient P would be between 0 and 0.02, as indicated by results from an unpublished pitot-static tube investigation, and thus the assumption that P equals zero would introduce negligible error. Equation (1) then becomes

$$\frac{H - H'}{H - p} = 0.6 \text{Lin}^2 \left(\frac{A_2}{A_1}\right)^2 \tag{3}$$

The estimated error in the measured total pressure at 0° angle of attack for the two pitot tubes based on measured dimensions and equation (3) are: 0.0006 and 0.0009 for the NAF No. 1 and the Kollsman type G-1 pitot tube, respectively. A comparison with the results presented in figure 3 shows that the experimental values at a Mach number of 0.2 are in excellent agreement with these estimated values.

Previous experimental results (reference 1) have shown that the magnitude of the error in the total-pressure measurements decreases slightly with increasing Mach number. It can be seen in figure 3 that the effect of compressibility on the total-pressure error of these pitot tubes is in agreement with the results of reference 1.

In an effort to determine the factors which produce a reduction in the magnitude of the total-pressure error with increasing Mach number the process whereby equation (3) was derived was repeated for compressible flows. It was assumed that the pressure at the drain hole was equal to stream static pressure, velocity V₁ was small, no losses were incurred in the flow up to the plane of the drain hole, and that the assumed discharge coefficient 0.8 was constant. The resulting equation is:

$$\frac{H - H!}{H - p} = 0.64N^{2} \left(\frac{A_{2}}{A_{1}}\right)^{2} \frac{\rho}{\rho_{H}} \frac{1}{1 + \frac{M^{2}}{4} + \frac{M^{4}}{40} + \frac{M^{6}}{1600}}$$
(4)

If the subscripts i and c are used to differentiate the incompressible and compressible forms, respectively, then:

$$\left(\frac{H - H'}{H - p} \right)_{c} = \left(\frac{H - H'}{H - p} \right)_{i} \frac{\rho}{\rho_{H}} \frac{1}{1 + \frac{M^{2}}{4} + \frac{M^{4}}{40} + \frac{M^{6}}{1600}}$$
 (5)

Since the last two terms of equation (5) decrease with increasing Mach number, the relation shows that the total-pressure error should decrease with increasing Mach number. Further, the largest contributing factor to this decrease is the change in density. The effect of compressibility on this error as determined by equation (5) is shown in figure 4.

The results of the calibration tests on the NAF No. 1 pitot tube at various angles of attack are presented in figure 5. It can be seen that the angular range wherein the error is essentially equal to the value at 0° is limited to approximately ±10°, although the rate of change of error with angle of attack beyond 10° is not large compared to that for a simple pitot tube. (See reference 3.)

A comparison of the results for the positive and negative conditions at a given angle of attack shows that

the differences are generally within the scatter of the test points.

An examination of the test results and the curve giving the limiting error for a reduction in velocity of 1 mile per hour under standard conditions shows that the angular range for this limiting error decreases from #240 at a Mach number of 0.2 to #210 at a Mach number of 0.5.

It can be seen that the effect of compressibility on the error, even at the higher angles of attack, is in agreement with the results shown in figure 3 and reference 1. The change in the magnitude at these higher angles of attack is such that the error at a Mach number of 0.5 is approximately 80 percent of the error at a Mach number of 0.2. It is interesting to note that a change of 86 percent would have been predicted by equation (5) or figure 4 although no effect of angle of attack was considered in the derivation of equation (5).

CONCLUDING REMARKS

The error in total pressure indicated by a pitot tube with drain holes at small angles of attack can be estimated, and this estimated value or an experimentally determined value can be extrapolated to higher speeds. These calibration tests indicate that the accuracy of the estimated values will be within reasonable limits.

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REFERENCES

- 1. Hensley, Reece V.: Calibrations of Pitot-Static Tubes at High Speeds. NACA ACR, July 1942.
- 2. Kiel, G.: Total-Head Meter with Small Sensitivity to Yaw. NACA TM No. 775, 1935.
- 3. Humphreys, Milton D.: Effects of Compressibility and Large Angles of Yaw on Pressure Indicated by a Total-Pressure Tube. NACA RB No. L5C30, 1945.

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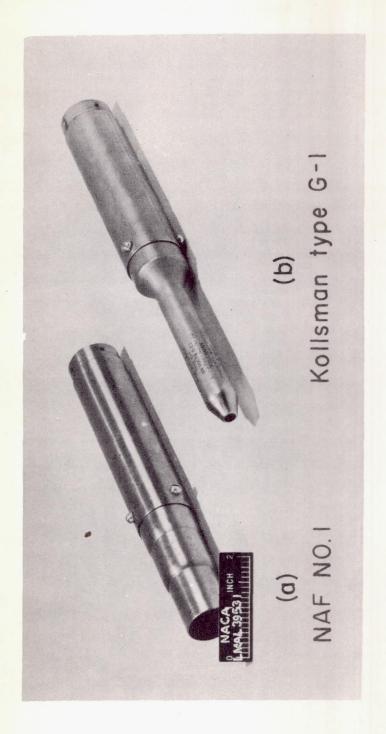


Figure 1.- Pitot tubes.

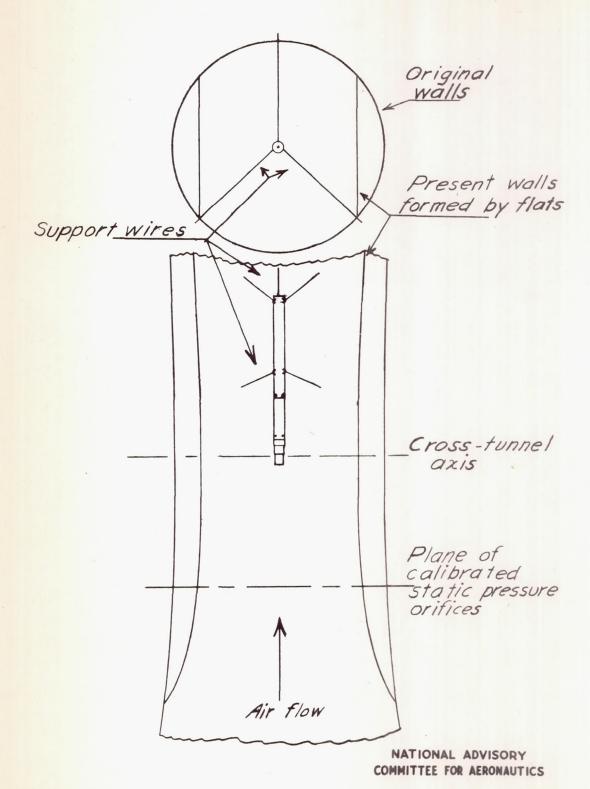


Figure 2 - NAF no. 1 pitot tube mounted in the test section of the 24-inch high-speed tunnel for calibration

